

Hunt for the Quark Gluon Plasma



The Quark Gluon Plasma as an Unicorn.
Experimentalists are the hunters, so....“All theorists are...”

Dilepton and Photons near T_c in the “semi”-QGP

[arXiv.org: 1409.4778](https://arxiv.org/abs/1409.4778) : the “*Gang of Nine*”:

Analytic computations:

BNL & RIKEN/BNL: RDP, Shu Lin

RIKEN/BNL → ECT Trento: Daisuke Satow

RIKEN Wako: Yoshimasa Hidaka

BNL → Western Michigan → RIKEN/BNL: Vladimir Skokov

Plus hydrodynamics (MUSIC):

McGill: Charles Gale, Sangyong Jeon, Jean-Francois Paquet, Gojko Vujanovic

The Quark-Gluon Plasma *near* T_c

Low T to $\sim T_c$: effective models - hadronic resonance gas, χ perturbation theory....

High T to $2?T_c$: (resummed) Hard Thermal Loop perturbation theory -

N. Haque, M. Mustafa, Mike Strickland, Nan Su + ...

How to treat the region *near* T_c ? (T_c to $2?T_c$)

Experimentally, important at *both* RHIC and the LHC

Models which treat *dynamical* processes:

Quasi-Particle: Peshier & Cassing; Bratkovskaya, Cassing, Linnyk, Toneev...

Center Domains: Masayuki Asakawa, Steffan Bass, Berndt Muller

Magnetic Plasma: Liao, Shuryak

AdS/CFT: holography, top down, bottom up...

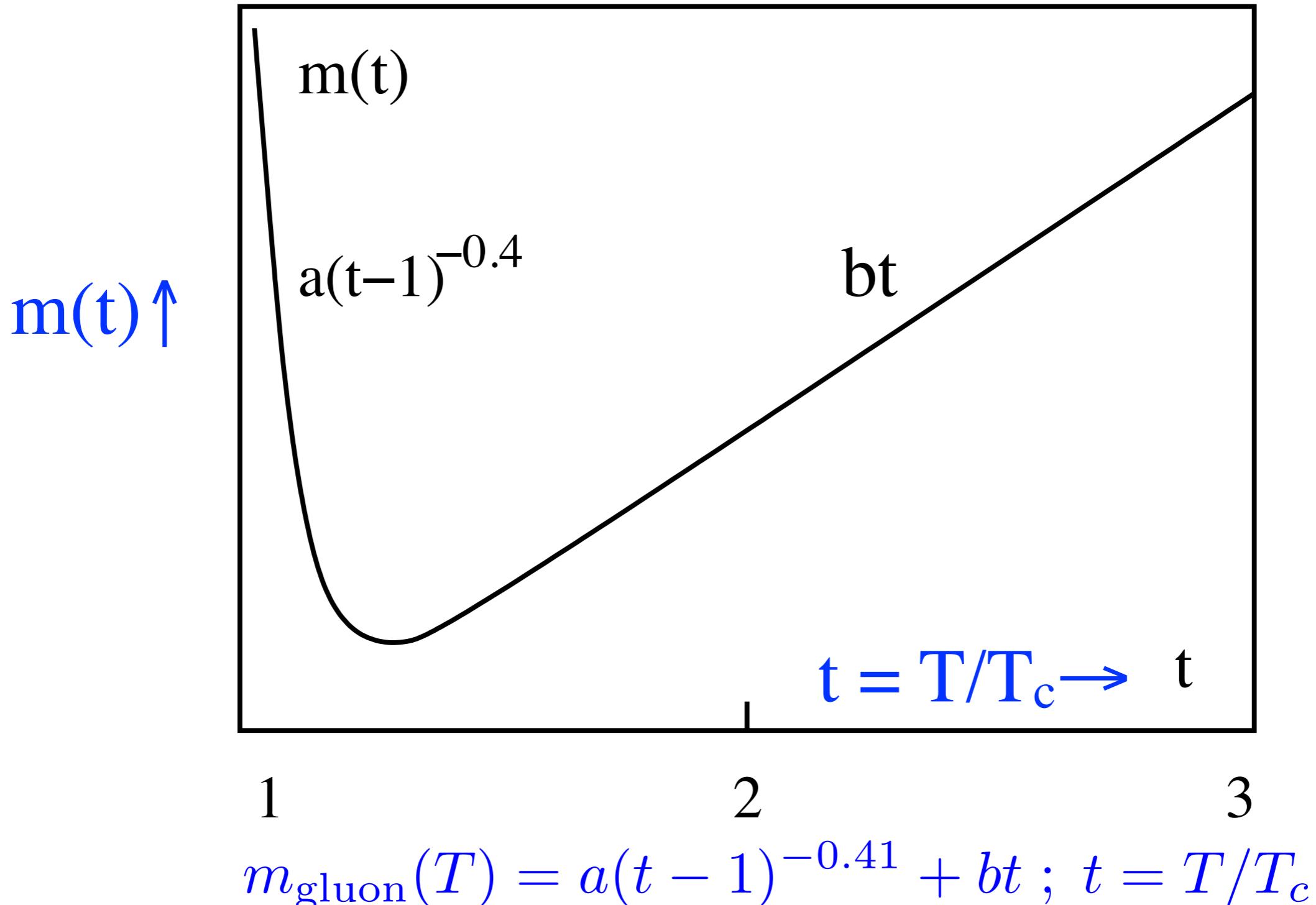
“Semi”-QGP

Quasiparticle Models

Castorina, Miller, Satz 1101.1255:

$T > 1.2 T_c$: “perturbative” quasi-particles, quasi-particle mass $m \sim T$

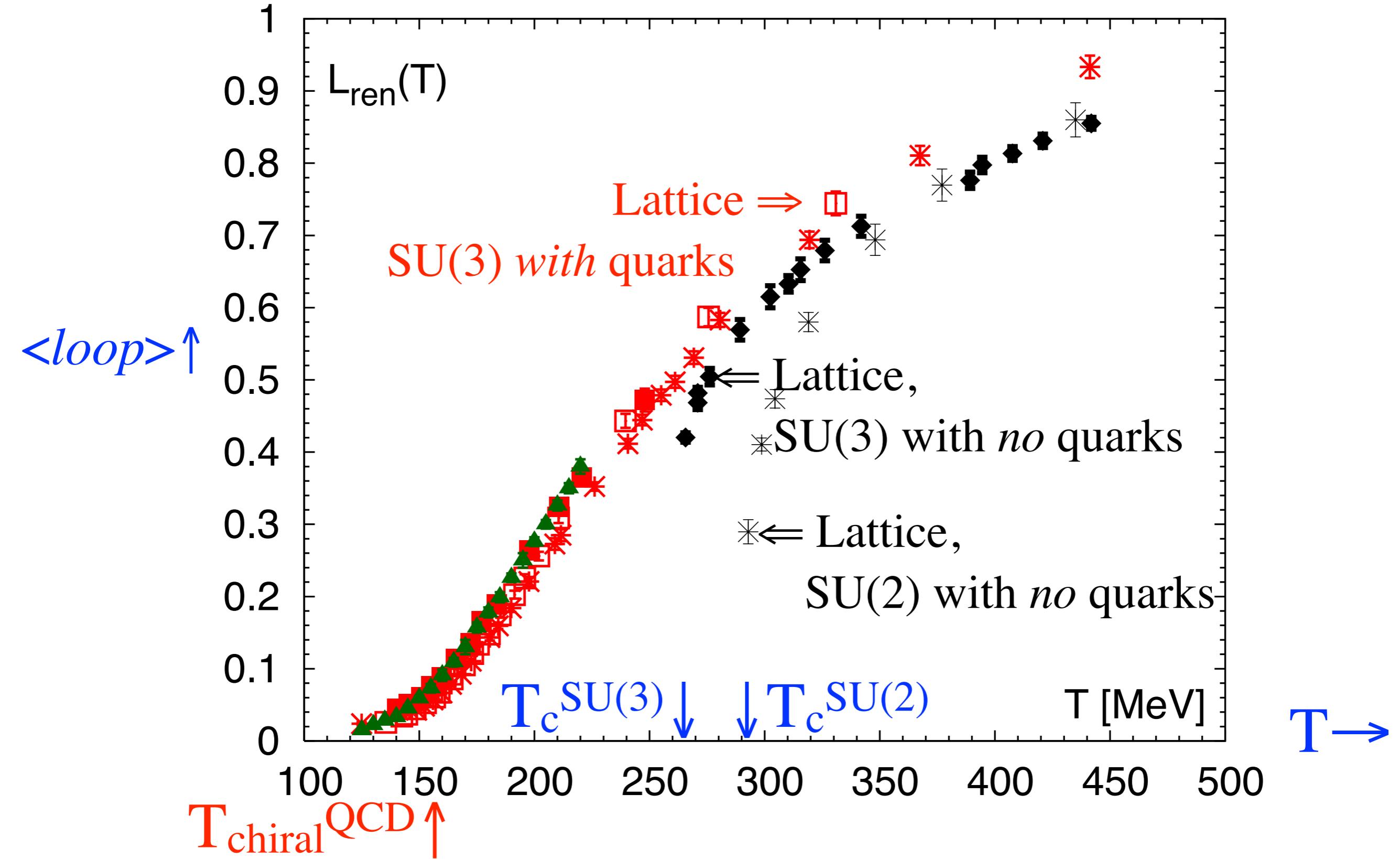
$T < 1.2 T_c$: quasi-particles become *very* heavy, $m \sim 1/(T - T_c)^{0.4}$, to get *small* pressure



Lattice: Polyakov Loop with and without quarks

Polyakov Loop: order parameter for deconfinement.

Lattice: Bazavov & Petreczky, 1110.2160



Semi-QGP

Polyakov Loop:

$$\ell = \frac{1}{3} \operatorname{tr} \mathcal{P} \exp \left(i g \int_0^{1/T} A_0 d\tau \right)$$

Simplest approximation to give a non-trivial loop: constant, diagonal A_0 :

$$A_0^{cl} = \frac{2\pi}{3} T \frac{1}{g} q(T) \lambda_8 \quad \lambda_8 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

Depends upon single function, $q(T)$, from fit to the pressure(T)

Easy to analytically continue to processes in real time: for quarks,

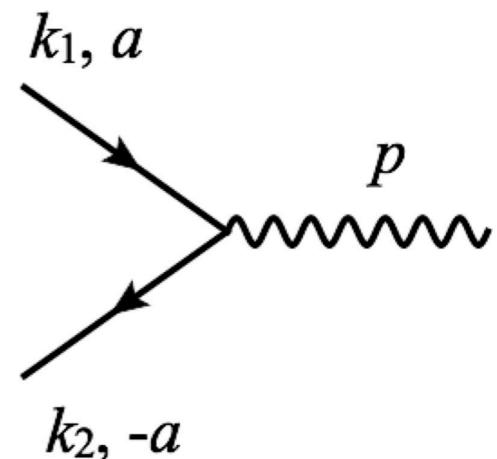
$$p_0 \rightarrow 2\pi T(n + 1/2 + q \lambda_8), \quad n = 0, \pm 1, \pm 2 \dots$$

Like an imaginary chemical potential for color (except gluons get it, too)

Need to use “double-line” notation for color ('t Hooft) generalized to finite N_c .

Dilepton production

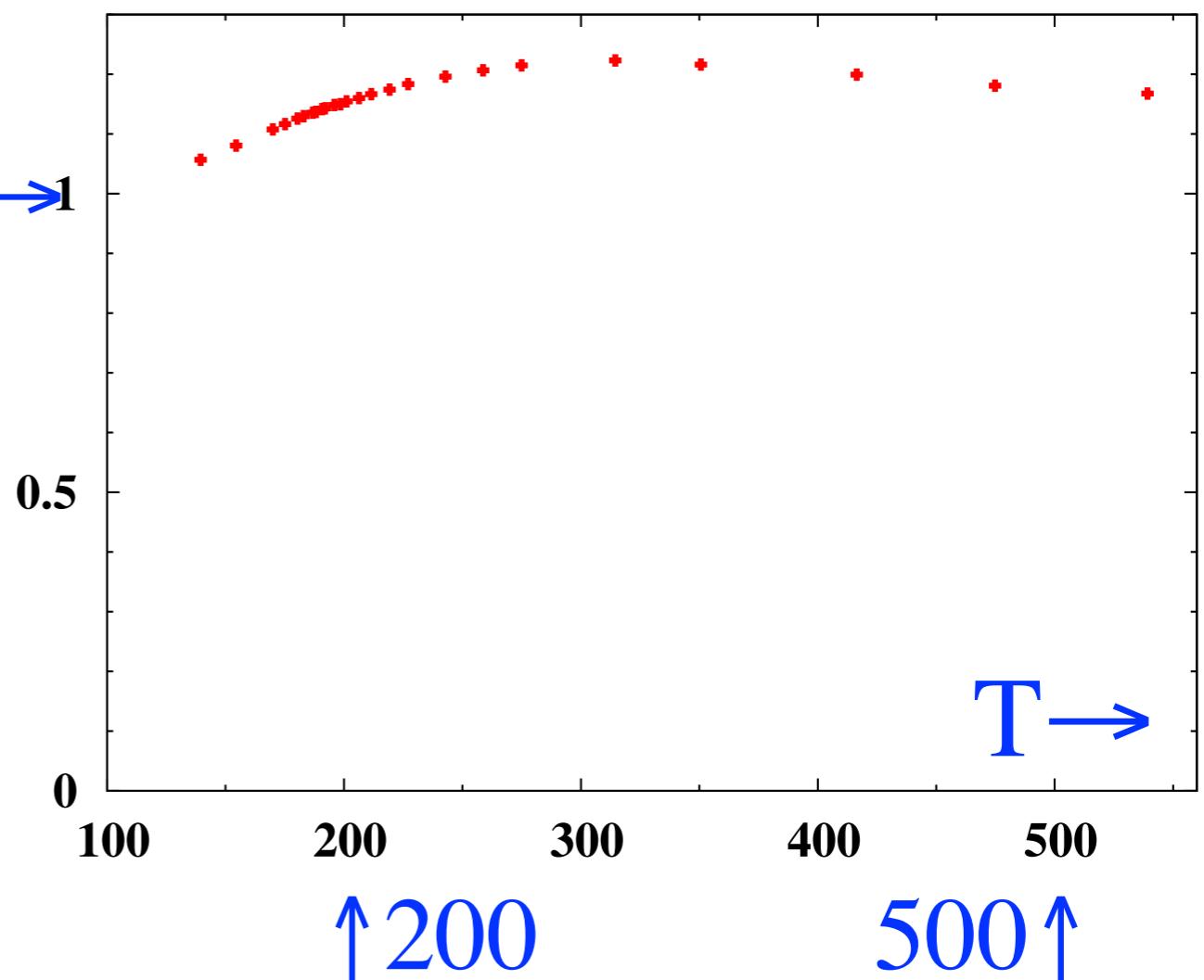
Compute to lowest order in g with $A_0^{\text{cl}} \neq 0$,
Off-shell photon goes to quark anti-quark pair.
Color “chemical potential” for anti-quark = *minus* that for the quark



High energy: Boltzmann statistics, so q’s *cancel*
Low energy: Bose-Einstein enhancement in *confined* phase!

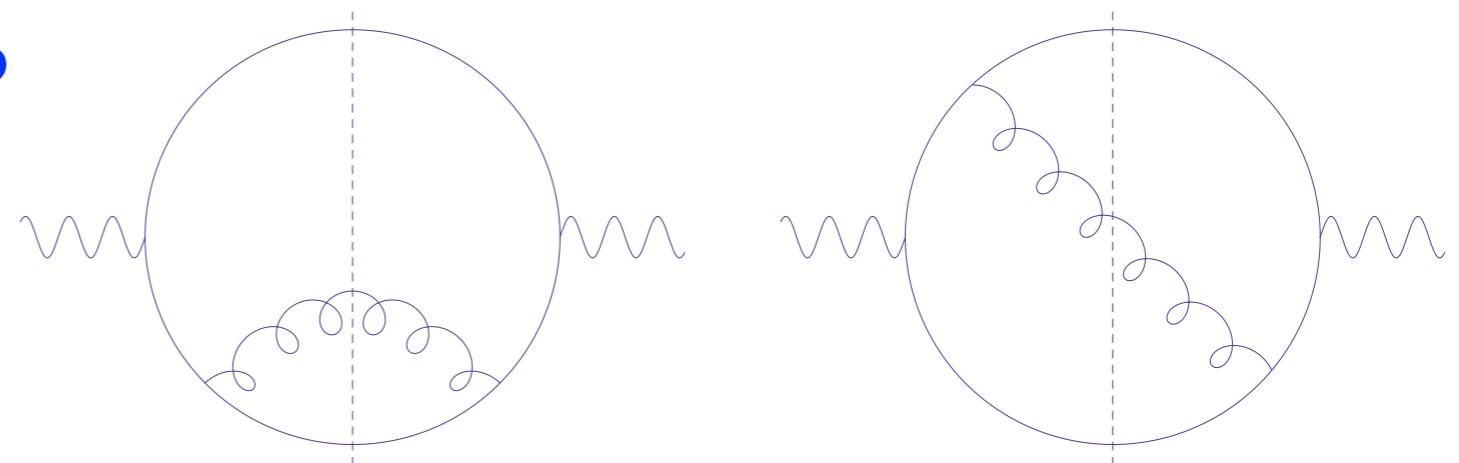
Ratio of dilepton production \Rightarrow
semi-QGP to perturbative
Same g , same T , only change $q(T)$

More dileptons in the confined phase.
Similar to condensate for A_0^2 :
Lee, Wirstam, Zahed, Hansson ‘98



Photon production

Due to kinematics, on-shell photon to quark anti-quark *plus* gluon

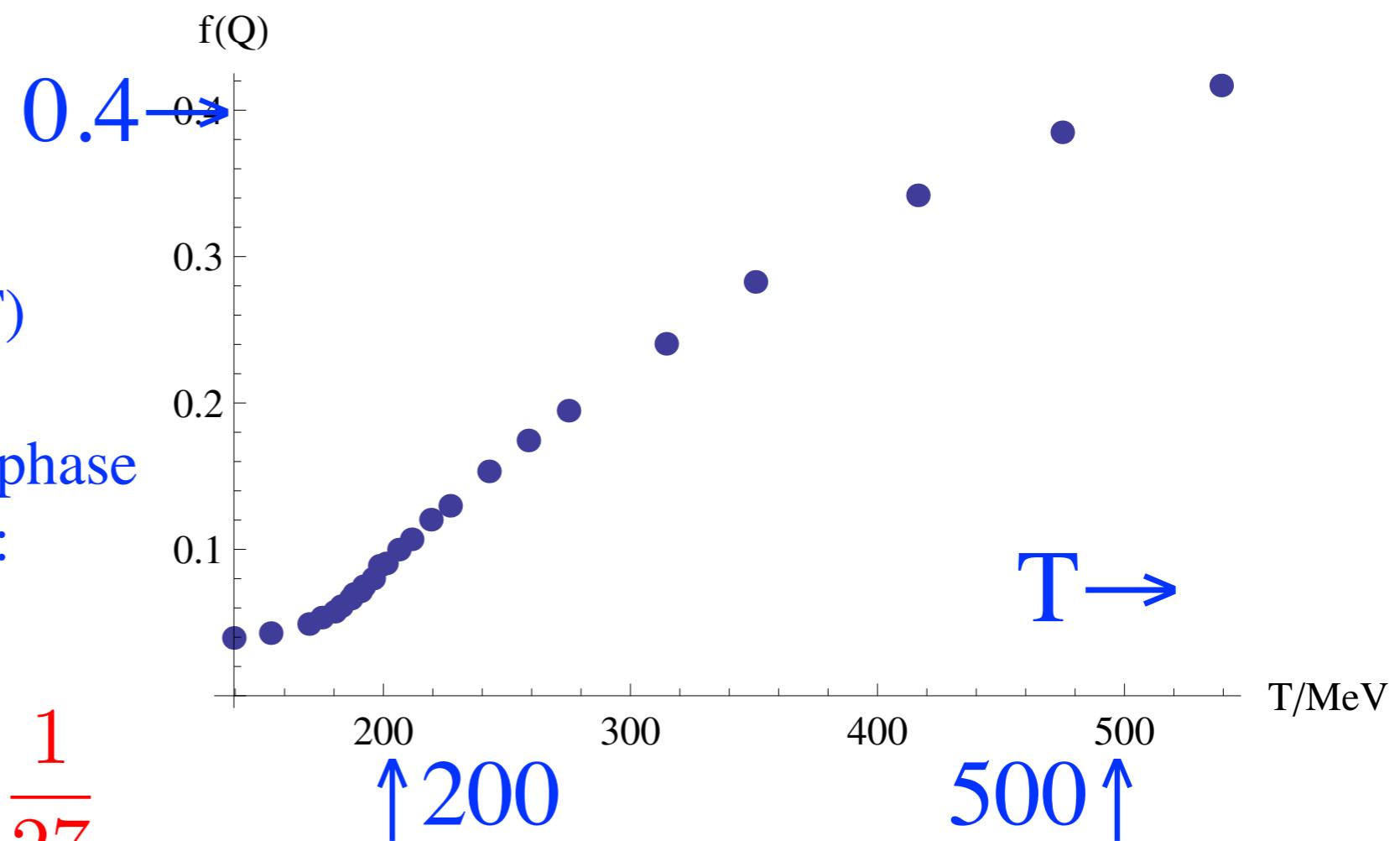


“Chemical potential” for quark and anti-quark do *not* cancel

Ratio of photon production \Rightarrow
semi-QGP to perturbative
Same g , same T , only change $q(T)$

Many fewer photons in confined phase ratio confined/perturbative phase:

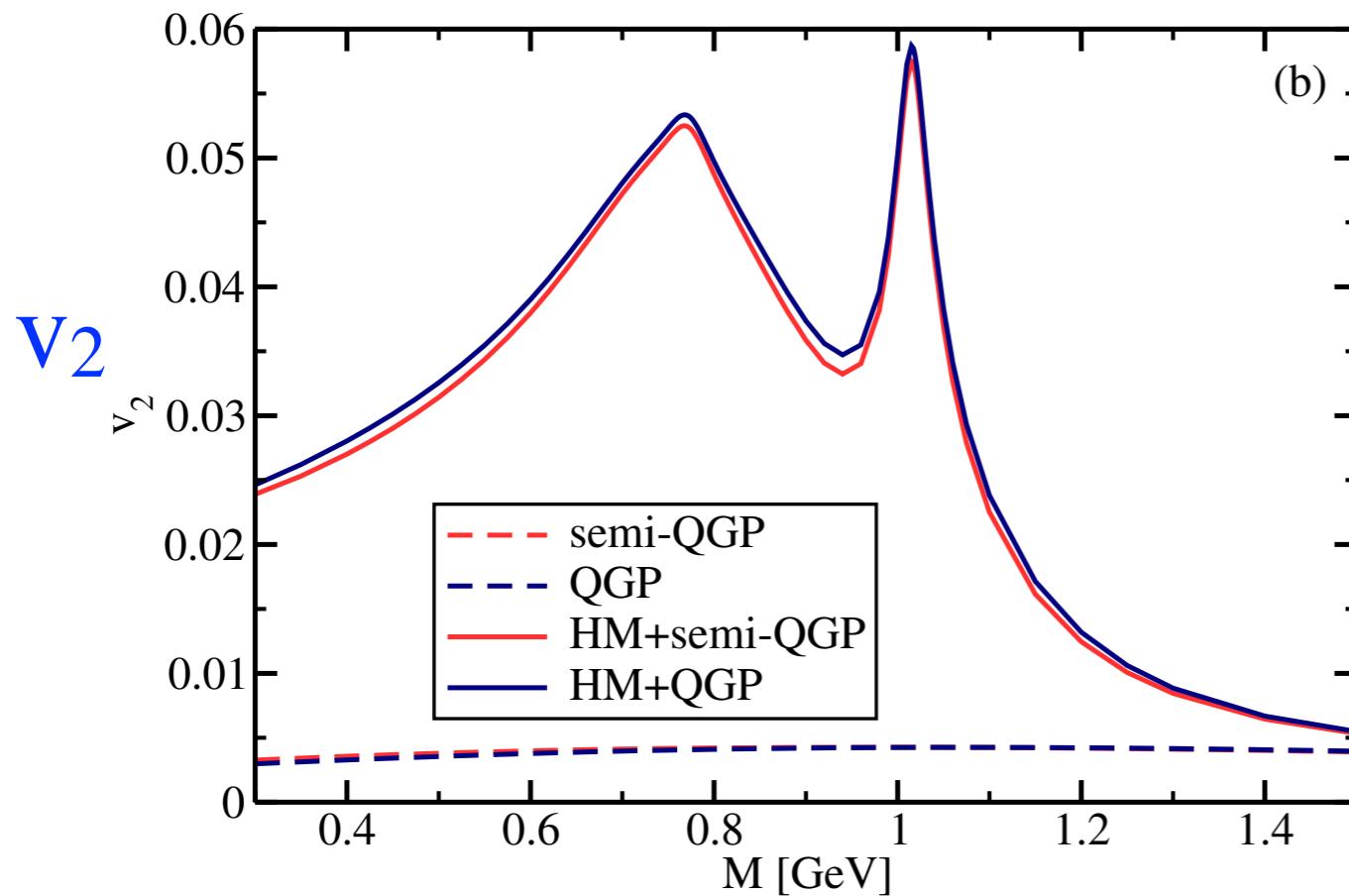
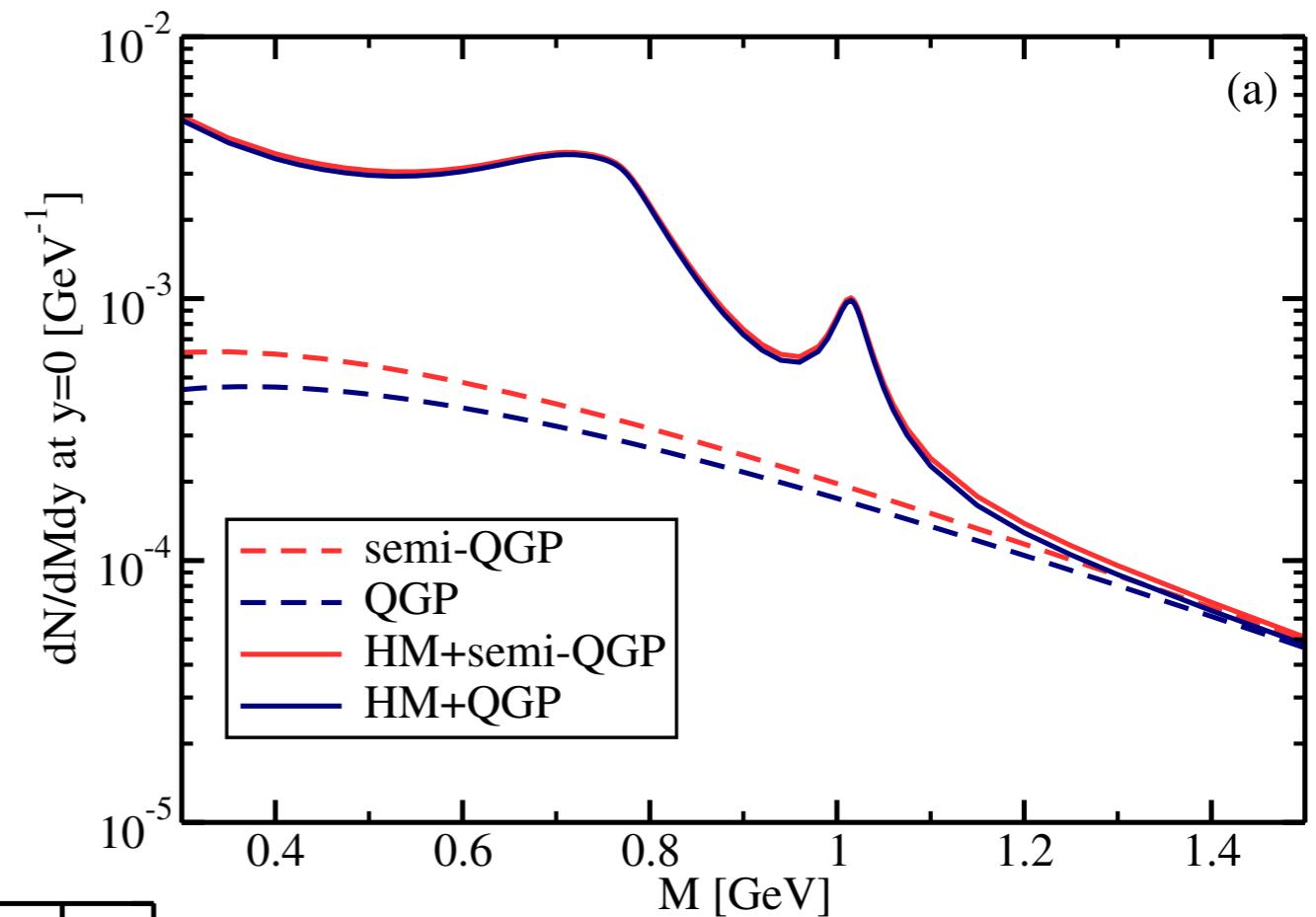
$$\#\gamma \left(\frac{\text{conf}}{\text{pert}} \right) = \frac{1}{3N_c^2} = \frac{1}{27}$$



Hydrodynamics: dileptons

MUSIC: 3+1 hydro @ RHIC:
 $\sqrt{s} = 200 \text{ GeV/A}$, central collisions
Preliminary analysis: only ideal hydro

Dileptons dominated by hadronic phase
Uniformly small v_2 .



Hydrodynamics: photons

In semi-QGP, *far* fewer photons above T_c .

Big effect on total v_2 :
tends to bias the total v_2 to that
in the hadronic phase
Small “dilution” by QGP phase

*Possible solution to experimental puzzle
of “big” v_2 for photons?*

